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PILOTING OF FLYING BOATS WITH SPECIAL REFERENCE TO PORPOISING AND SKIPPING

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SUMMARY

The various types of hydrodynamic instability - including porpoising, skipping, and yawing - that may be encountered during take-off or landing of a flying boat are described and the piloting technique required for efficient take-offs and landings is discussed. Suggestions are made for assisting a pilot to become familiar with the take-off and landing qualities of a flying boat that is new to him.

INTRODUCTION

The possibility that porpoising, skipping, or yawing will occur during take-off or landing of flying boats presents a great hazard in their operation. Recent trends in the design of flying boats appear to have increased the probability that the pilot will inadvertently encounter one or more of these types of instability. It is very important, therefore, for the pilot to be sufficiently familiar with the types of instability to recognize the approach of danger during take-offs and landings. Ability to distinguish among the various types of instability is therefore essential if the pilot is to employ the technique required either to avoid the instability or to recover safely after the instability is encountered.

The purpose of the present paper is to describe the types of instability that may be encountered in the operation on calm water of flying boats of current design and to emphasize some of the precautions that may be taken by the pilot in order to minimize the time and distance required for take-off and to avoid much of the danger resulting from instability. The operation of flying boats in rough water presents additional problems not

discussed herein. The information contained in this report is of a very general type and was collected from a number of published papers, which are given in a bibliography. More detailed discussions of the various subjects covered herein may be found in the papers listed in the bibliography.

TYPES OF INSTABILITY

Porpoising of flying boats or float seaplanes is an oscillation in trim and in draft and may occur during either take-off or landing at any speed from the hump speed to the get-away speed. Two distinct types of porpoising are recognized as possible with all conventional designs of hulls and floats. The two types are designated low-angle porpoising, which occurs at relatively low trim, and high-angle porpoising, which occurs at relatively high trim. In low-angle porpoising the craft rides on the planing area forward of the step, and that part of the planing bottom aft of the step is ordinarily out of the water. In high-angle porpoising parts of the planing bottom both forward and aft of the main step are in the water. The two types are illustrated in figure 1.

Skipping, which refers to a type of instability in which the airplane momentarily leaps out of the water, may occur during either take-off or landing. Under certain conditions high-angle porpoising may appear (fig. 1(b)) and increase in violence with increase in speed until skipping occurs (fig. 2).

Yawing instability, as used in the present discussion, is a tendency for the airplane to swerve from a straight course on the water. This tendency is likely to occur near the hump speed and at speeds near get-away. The swerving at speeds near get-away, which may resemble a ground loop, is generally associated with unusually low angles of trim and may also be associated with low-angle porpoising.

IMPORTANCE OF TRIM

Trim may be defined as the inclination of the keel of the forebody at the step or as the inclination of any

other arbitrary base line of the hull. The forces acting on the bottom of a hull are affected by the trim in a manner analogous to that in which the forces acting on the wing are affected by the angle of attack of the wing. Trim is one of the most important variables that must be used in describing the characteristics of a flying boat or float seaplane. At any given speed and load there is one best value of the trim that will result in the least resistance and the greatest acceleration with the power available. There is generally a limited range of trim angles for which no porpoising will occur, and it is highly desirable that the trim for least resistance lie within this range of trim at all speeds and loads likely to be encountered. The safest and most efficient piloting technique for take-off, then, requires that the trim be held within the stable range and as near the "best" trim as is possible with the control normally available to the pilot.

DISCUSSION

Porpoising

At any speed above the hump speed and below get-away there is, in general, a range of trims for which no porpoising will occur. Within this stable range any motions resulting from a transient disturbance, which might be caused by hitting a single wave, will be damped out quickly. This stable range is bounded by well-defined limiting values of the trim. The flying boat will not run steadily at trims either below the lower limit or above the upper limit.

Figure 3 shows the variation of these trim limits with speed. The graph represents no specific airplane but shows results typical of those obtained from tests of models and full-size flying boats currently used by the U. S. Navy. Figure 3 may conveniently be interpreted by assuming that the airplane is running at some constant speed - for example, 50 knots - and that the elevators are at the neutral position. The flying boat would then have a trim of 7.5°, which is within the stable range, and no porpoising would occur. At the speed of 50 knots the lower trim limit is shown to be 4.5° and, if the pilot were to move the control column forward very gradually, no porpoising would occur until the airplane was trimmed down to the lower trim limit. If the pilot held

the control column fixed to give a trim slightly greater than 4.5°, porpoising would not occur spontaneously, but the oscillations resulting from a transient disturbance would not damp out as quickly as if the trim were well within the stable range. If, then, the pilot resumed the gradual motion of the control column forward, low-angle porpoising would appear spontaneously as the trim crossed the lower limit. At first the porpoising would be rather small in amplitude and not dangerous but, if the control column were gradually pushed farther forward, the amplitude of the porpoising would increase more and more and the porpoising would become dangerous with increased departure from the lower trim limit.

If, again, the flying boat is assumed to be running at a constant speed of 50 knots with elevators neutral and at a trim of 7.5° and the pilot gradually pulled back on the control column, the trim would increase without the appearance of porpoising until the trim exceeded 9.8°. In an idealized case of perfectly calm water and calm air, the trim could be gradually increased up to about 10.7° and no porpoising would occur but, at trims above 10.7°, dangerous high-angle porpoising would appear spontaneously and continue indefinitely. In most actual cases an external disturbance, such as a wave, would cause porpoising to appear at some trim between 9.8° and 10.7°. The resulting motions would not damp out unless the pilot pushed forward on the control column to reduce the trim to some value below 9.8°. The trim limit that has a value of 9.8° in the particular case and speed cited is designated the lower branch of the upper limit or the upper limit with decreasing trim. This term originated because it refers to the trim of the airplane at which recovery from high-angle porpoising occurs as the control column is gradually pushed forward in order to decrease the trim from the unstable region into the stable region. The uppermost trim limit is designated the upper branch of the upper limit or the upper limit with increasing trim.

The three trim limits shown in figure 3 are typical of flying boats in current usage but variations will be found for different types of hull. An increase in the weight carried by the hull moves all three limits to higher trims and higher speeds. An increase of 10,000 pounds in the gross weight of a 50,000-pound flying boat, for instance, would raise the limits about 1°. For a given gross weight an increase in wing lift

such as might be caused by an increase in the flap deflection would reduce the load carried by the hull and would thereby reduce the trim limits; likewise, a head wind would increase the wing lift and lower all the trim limits of stability.

When heavy seas and high winds are encountered, the stability characteristics will be greatly modified; however, generalizations regarding the optimum piloting technique under these conditions are not proposed in the present report. Some aspects of the problems involved in porpoising (and skipping) must be subordinated to those resulting from the wind and waves. Experienced pilots often find it necessary to hold the trim very high to minimize the wetting of the propellers and pounding of the hull and it is sometimes necessary to deal with large waves individually as they are encountered.

Skipping

The most violent type of skipping is a form of instability that involves "sticking" of the afterbody at speeds near get-away. Recent investigations have shown that sticking is usually associated with insufficient depth of step and may be practically eliminated by suitable design. Experience has shown that, if a flying boat does exhibit this violent form of instability, the instability may occur either on take-off or on landing but the greatest danger appears to be in landing at relatively high trims. Specifically, if the trim at contact is equal to or greater than that when the keel of the afterbody is horizontal (the average for current designs is about 6°), there is danger that the flying boat may skip off the water one or more times and then go into a stall at a dangerously low altitude. With a flying boat that exhibits sticking of the afterbody, the hazard due to skipping appears to be greatly lessened if trims relatively low, but not low enough to encounter low-angle porpoising, are used in take-off or landing. These trims necessitate landing and taking off at relatively high speeds. A full-stall landing might also presumably be made without much danger from skipping because the speed after landing would be sufficiently low to prevent subsequent flight off the water, although some high-angle porpoising would be very likely to occur.

The type of skipping described in the foregoing paragraph is very different from the much more gentle motions that may occur either as a light recoil from the landing impact or as a difference between the attitude of the flying boat while it is in the air and the attitude it assumes immediately after landing. Any tendency to recoil lightly or to skip may be readily observed in the wave pattern in the wake of a flying boat.

Skipping characteristics appear not to be affected to any important extent by normal variations in loading, flap setting, or head wind except insofar as the trim at landing is affected.

Yawing Instability

Yawing instability of flying boats may be encountered at either of two speed ranges. At speeds near the hump speed, multiengine airplanes exhibit a tendency to yaw and may not be controllable except by use of more power on one side than on the other. This yawing tendency disappears after the flying boat begins to plane on the forebody during a take-off. At higher speeds, near the get-away or immediately after landing, dangerous yawing may be encountered if the flying boat is allowed to trim too low. This high-speed yawing may be associated with low-angle porpoising and may sometimes lead to a water loop in the region of speed and trim shown in figure 3.

Location of Center of Gravity

Variations in the loading of fuel, cargo, and personnel are likely to vary the position of the center of gravity sufficiently to have an important effect on the porpoising characteristics. For all practical purposes, the effect is merely that due to a variation in the trim assumed by the flying boat. This effect is shown in figure 4, in which trim is plotted as a function of speed for four locations of the center of gravity and for two positions of the elevators. Trim limits are included and porpoising is indicated when the trim is outside the stable range. With the center of gravity unusually far forward, the airplane is more likely to trim below the lower limit and to encounter low-angle porpoising. With the center of gravity unusually far aft, high-angle porpoising is more likely to be encountered. In general, however,

sufficient elevator control is available to offset these tendencies to a large extent.

Numerous investigations have been made of the way in which the location of the center of gravity affects the stability characteristics. Figure 5 presents typical results to show the maximum amplitude of any porpoising that occurred during take-offs with elevator either full up or neutral and with the flaps deflected 20°. For example, no porpoising occurred with either neutral or full-up elevator when the center of gravity was anywhere between 29.4 and 32 percent mean aerodynamic chord. The stable range of center-of-gravity positions, however, would be considerably increased if the elevator were deflected up or down as required when the center of gravity was, respectively, forward or rearward of 30 percent of the mean aerodynamic chord.

A comparison of figures 5(a) and 5(b) shows that the stable range of location of the center of gravity is greater for the light load than for the heavy load.

Because flaps have a large effect on the trim of a flying boat, the stable range of center-of-gravity location varies widely with flap deflection. Figure 6 shows the variation of stable range of the center-of-gravity location with flap deflection. For this graph it has been assumed that porpoising of 2° in amplitude is permissible and that either neutral or full-up elevator may be used. The permissible fore and aft locations of the center of gravity were then plotted as a function of flap setting. Figure 6 may be used to show clearly that violent porpoising may occur as a result of unintentional change in flap deflection preceding or during take-off. With the center of gravity at 30 percent of the mean aerodynamic chord and with the flaps down 20°, the pilot could use the elevator at any deflection between neutral and full up at any speed during the take-off and the porpoising would never exceed 2° in amplitude. With the flaps at 30°, however, excessive low-angle porpoising would be encountered with neutral elevator. With the flaps at 0° violent high-angle porpoising would result from the use of full-up elevators.

Several large flying boats have been lost during attempted take-offs in which the flaps were deflected

considerably more than was customary. Official accounts of these accidents vary in detail but resemble each other in reporting that porpoising occurred during attempted take-off and that the airplane bounced off the water one or more times before crashing. Similar accidents have occurred in attempted take-offs with the flaps in the usual position but with the center of gravity unusually far forward. It appears likely that, in some of these accidents, low-angle porpoising had first occurred and that the pilot, in order to recover, had followed the usual practice of applying up elevator and had then continued the take-off with elevator up, which led to high-angle porpoising.

TRIM INDICATORS

One difficulty that has limited the practical application of information regarding the effects of trim on stability and on resistance has been the apparent lack of satisfactory instruments for indicating the angle of trim. The bubble type of inclinometer is unsatisfactory because it is affected by the forward acceleration of the airplane. Efforts to employ a gyroscope with a more open scale than usual have been moderately successful for experimental purposes but the instrument has not appeared suitable for routine service. Some test pilots have used a graduated scale made by attaching several suitably spaced strings to the wind screen and have read the trim from the position of the horizon as seen against the scale; the use of the scale on the wind screen, however, requires accurate positioning of the pilot's eye with reference to the scale.

Another type of instrument that makes use of the natural horizon is shown in figures 7 and 8. This instrument, the NACA trim indicator, consists of lenses and mirrors arranged somewhat like a brilliant finder on a camera to focus an erect image of the horizon on a graduated scale. The accuracy of the readings of this type of instrument is not affected by the position of the pilot's eye. The many other duties of a pilot, however, may prevent him from devoting a great deal of attention to any form of trim indicator during take-off except during training and familiarization flights. In many cases it may therefore be convenient to locate a trim indicator in front of the copilot or another observer,

who could either read aloud the trim and airspeed or note deviations from a prearranged schedule of trim and airspeed.

TRAINING OF PILOTS IN TAKE-OFF TECHNIQUE

Stability.- Because of the hazards associated with porpoising, it appears that a pilot's training should include some experience in taxying on calm water to explore the stable range of trim of a flying boat that is new to him. A simple and rapid procedure is to accelerate the airplane quickly to some predetermined planing speed, for example, 50 knots, and then to throttle down the engines enough to maintain a constant speed. The control column may then be pushed forward from the neutral position very gradually and deliberately until low-angle porpoising is noted. When the porpoising is definitely established, but before it builds up to a dangerous amplitude, the control column may be pulled back gradually until the airplane trims above the lower limit and porpoising ceases. A similar procedure may be used in a subsequent run to determine the upper limits by pulling the control column back gradually from the neutral position until high-angle porpoising appears. The onset of high-angle porpoising may appear as an oscillation mainly in heave with very little rocking motion. In the low-angle porpoising the motion will likely be different, and an oscillation in trim may be the first indication to the pilot that the lower trim limit has been crossed.

Carrying out the familiarization tests may necessitate a shift in the center of gravity either forward or rearward of intermediate positions in order for the pilot to obtain a sufficient range of variation in trim. Efficient planning of the tests requires advance knowledge of the trim limits and of the stable range of the center of gravity. This information is usually obtained for a specific design in towing-basin tests of dynamic models and in flight tests of the airplane before it is accepted for service. From this information charts similar to figures 3 and 4 could be prepared for the particular airplane with the load to be used in the familiarization tests. With charts of this type as a guide, the pilot could explore the stable range of trims in three or four different taxi runs at several constant speeds ranging

from the hump speed to the highest speed considered safe. Only in exceptional cases would it be safe or of any value to explore either the upper or the lower limits at speeds near take-off. At speeds below the stalling speed it is a relatively simple and safe procedure to close the throttles and discontinue the run at any time that the porpoising appears to be getting out of control.

Resistance.- It has long been recognized that the time and distance required for the take-off of a flying boat will be unnecessarily great if the trim is not held as close to the best value as is possible with the control normally available to the pilot. At the hump speed flying boats frequently trim 5° or more above the best trim. The elevators are usually effective in varying the trim through a range of as much as 5° at the hump speed when full power is applied. It follows that down elevator should be used at the hump speed in most cases. At speeds slightly more than the hump speed, however, down elevator should be used with caution because it may lead to low-angle porpoising. At higher planing speeds the elevators are more effective, and no generalization can be made regarding the position of the elevators required to obtain low resistance without porpoising. The generalization can be made, however, that the best trim, referred to the forebody keel, for a large number of flying boats now in service does not vary greatly from an average of about 6° throughout the planing range.

The practice of rocking a seaplane at and near the hump speed is sometimes resorted to in an effort to reduce the water resistance and get on the step. There does not appear to be any reason why rocking should lower the resistance or assist in getting on the step except that, in the course of each rocking cycle, the trim of the airplane may approach or cross the best value. In the short interval when the trim remains close to best trim the resistance will be near a minimum and the airplane will be accelerated more than if the trim had been held continuously at some higher value. A much better result could be obtained if the trim were held continuously as near as possible to the best trim.

As a rough approximation, the minimum time and distance for take-off without porpoising may be obtained if the pilot (a) holds down elevator at speeds approaching and including the hump speed, (b) maintains the trim as

low as is practical without porpoising (but not lower than about 6°) for a short range of speeds above the hump, (c) maintains about 6° trim throughout the planing range, and (d) is careful to avoid a pull-up before a safe flying speed is reached. At speeds below the hump speed any advantage to be gained in holding down elevator may be outweighed in many cases by adverse effects on the bow wave and on the spray.

CONCLUDING REMARKS

Several precautions should be taken by the pilot of a flying boat of conventional design in order to take off in the least time and distance possible and at the same time to avoid much of the danger associated with porpoising, yawing, and skipping. The discussion in this paper was limited to take-off and landing in calm water, but the fundamental stability characteristics also apply, in a general way, to operations in rough water. The importance of porpoising, skipping, and yawing as compared with the importance of the waves to be encountered in any particular instance, however, must be evaluated on the basis of the personal observation and experience of the pilot. Subject to these restrictions the following precautions and procedures are suggested:

1. Preliminary to flying a boat that is new to him, the pilot should have available for study information regarding the trim limits of stability, the stable range of the center of gravity, the skipping characteristics, and the best trims of that particular design.

2. Consideration must be given to spray striking the propeller and other parts of the airplane. Within this limitation the elevator should be held down at speeds approaching and including the hump speed in order to pass the hump with a minimum of water resistance. Rocking of a flying boat to get on the step is unnecessary and is in general a less efficient technique than applying constant down elevator.

3. At speeds slightly more than the hump speed, low-angle porpoising will occur if the flying boat is allowed to trim too low. Abnormally large deflections of the flaps or unusually far forward positions of the center of gravity result in a tendency for the flying

boat to trim too low and cause low-angle porpoising. When the tendency occurs, it should be corrected by applying up elevator.

4. As the speed is increased well above the hump, excessive up elevator or attempted pull-up before a safe flying speed is reached should be avoided to prevent high-angle porpoising and skipping. High trims also result in excessive resistance during the high-speed planing.

5. Abnormally low trims (possibly 3° or less) should be avoided at speeds approaching get-away and on landing to prevent low-angle porpoising and ground looping.

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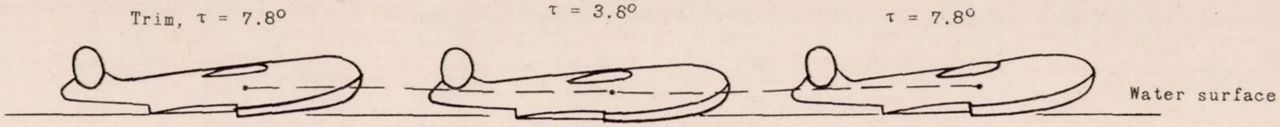
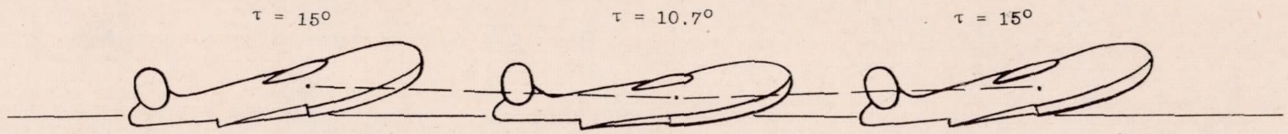


(a) Low-angle porpoising at 40 knots.



(b) High-angle porpoising at 58 knots.

Figure 1.- Typical sequence in the porpoising of a flying boat having a gross weight of 50,000 pounds.

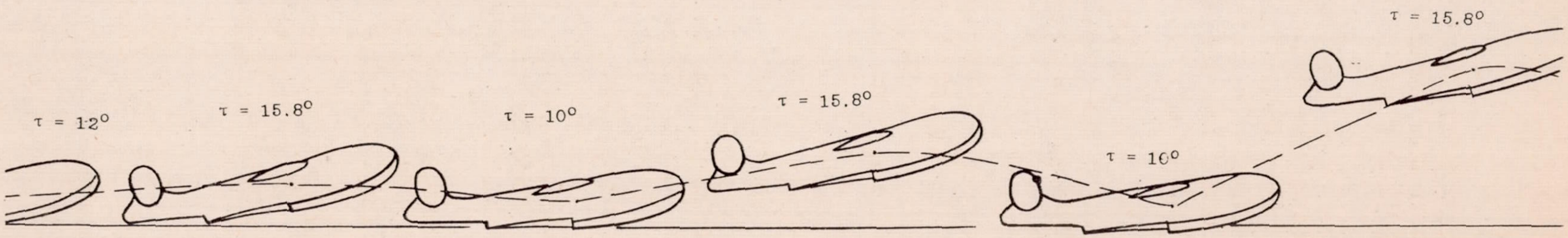


Figure 2.- Skipping of a flying boat near get-away. Gross weight, 50,000 pounds; speed, 75 knots.

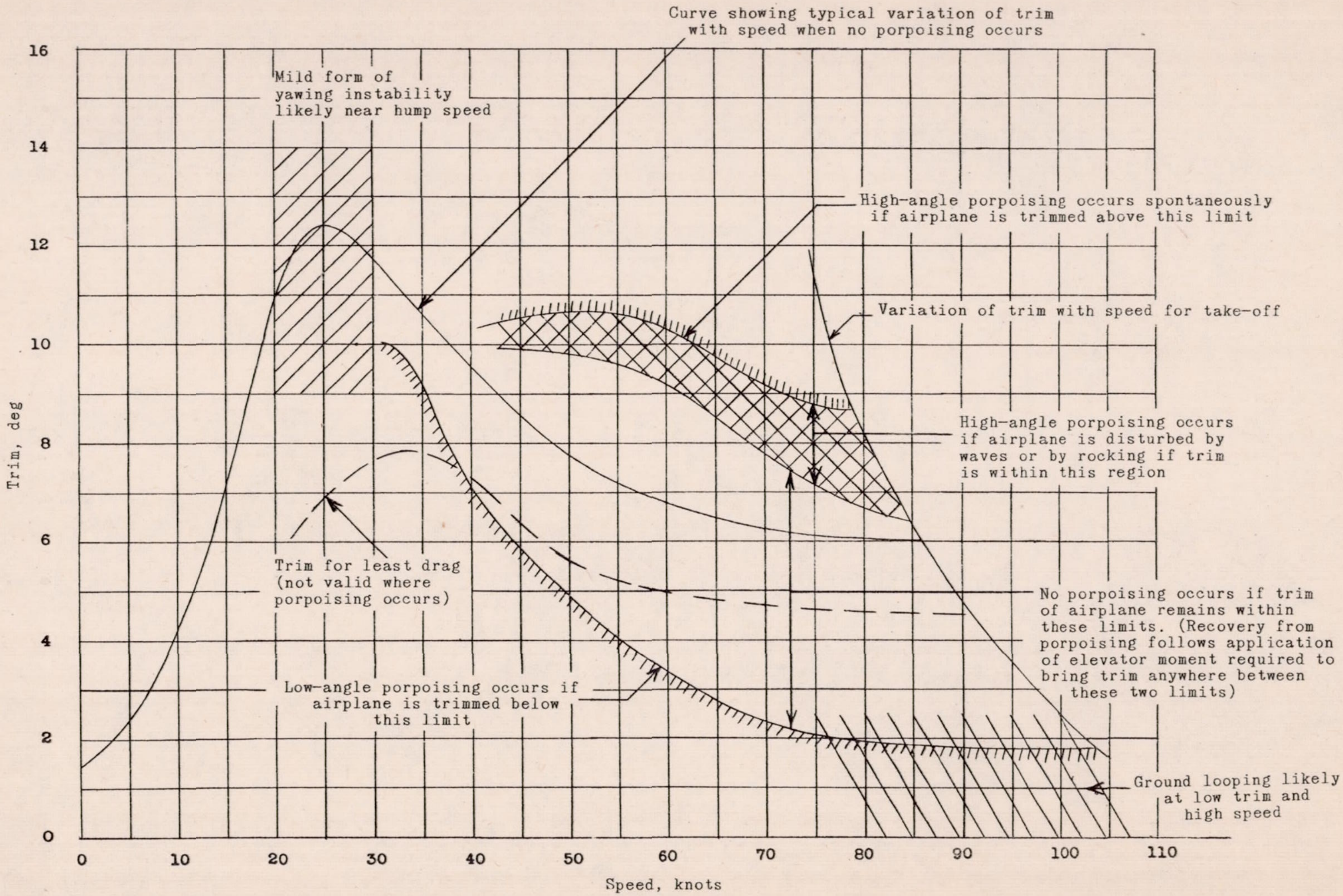


Figure 3.- Stable and unstable regions of speed and trim for a representative flying boat having a gross weight of 50,000 pounds.

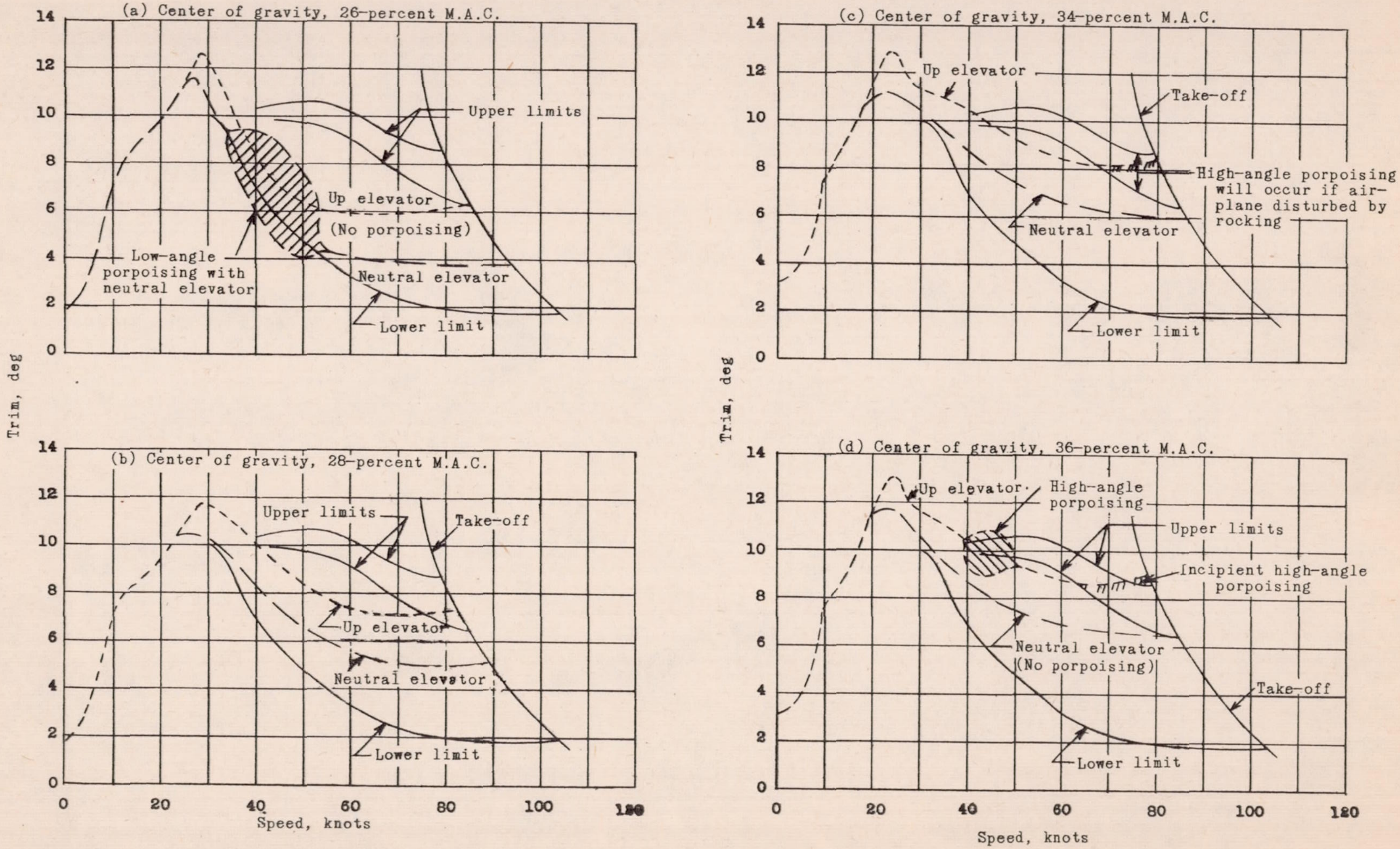


Figure 4.- Variation of trim with speed for neutral and full-up elevator with center of gravity at four different locations. Gross weight, 50,000 pounds; flap deflection, 20°.

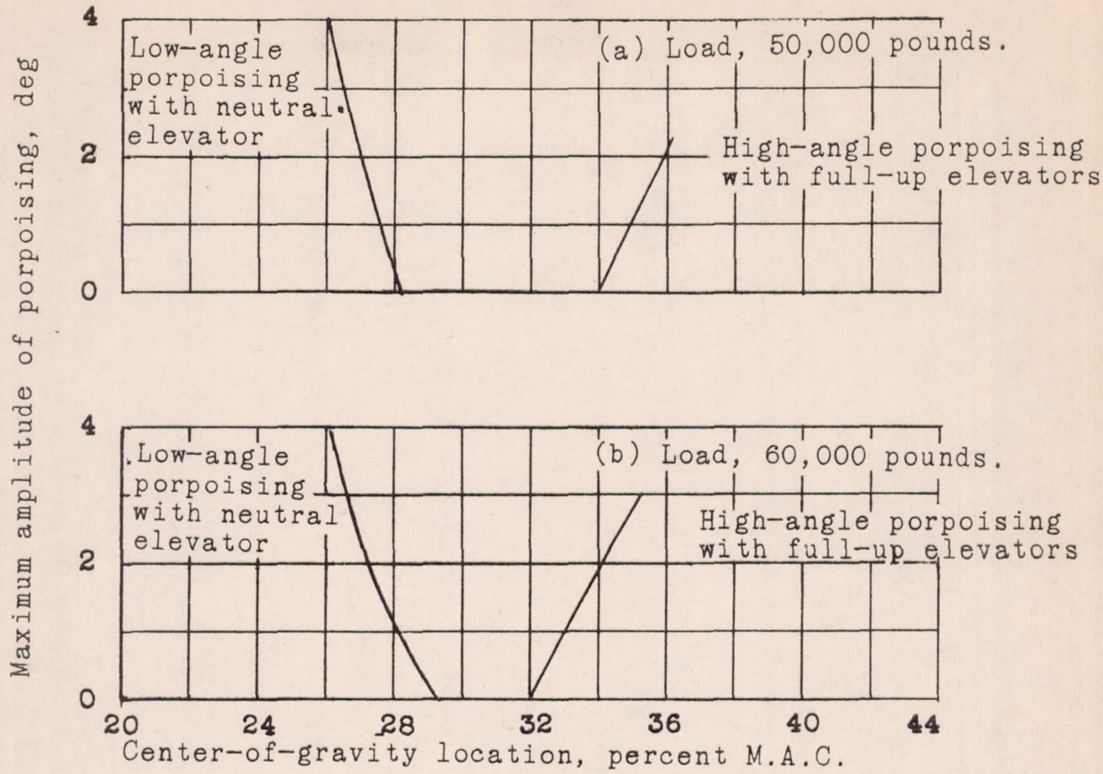


Figure 5.- Variation of amplitude of porpoising with location of the center of gravity. Flaps deflected 20°.

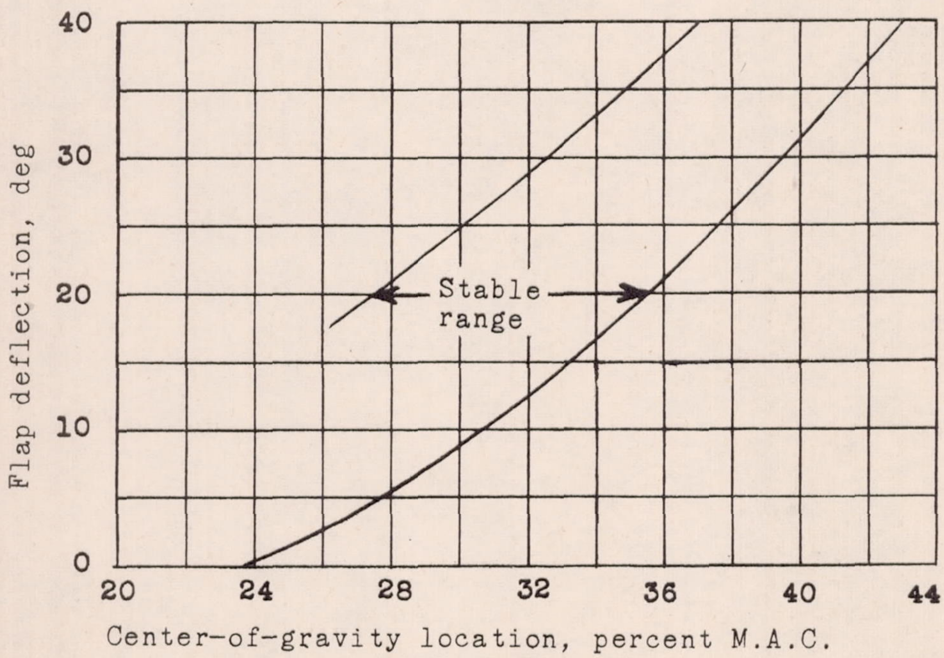


Figure 6.- Effect of flap deflection on the stable range of the center-of-gravity locations.

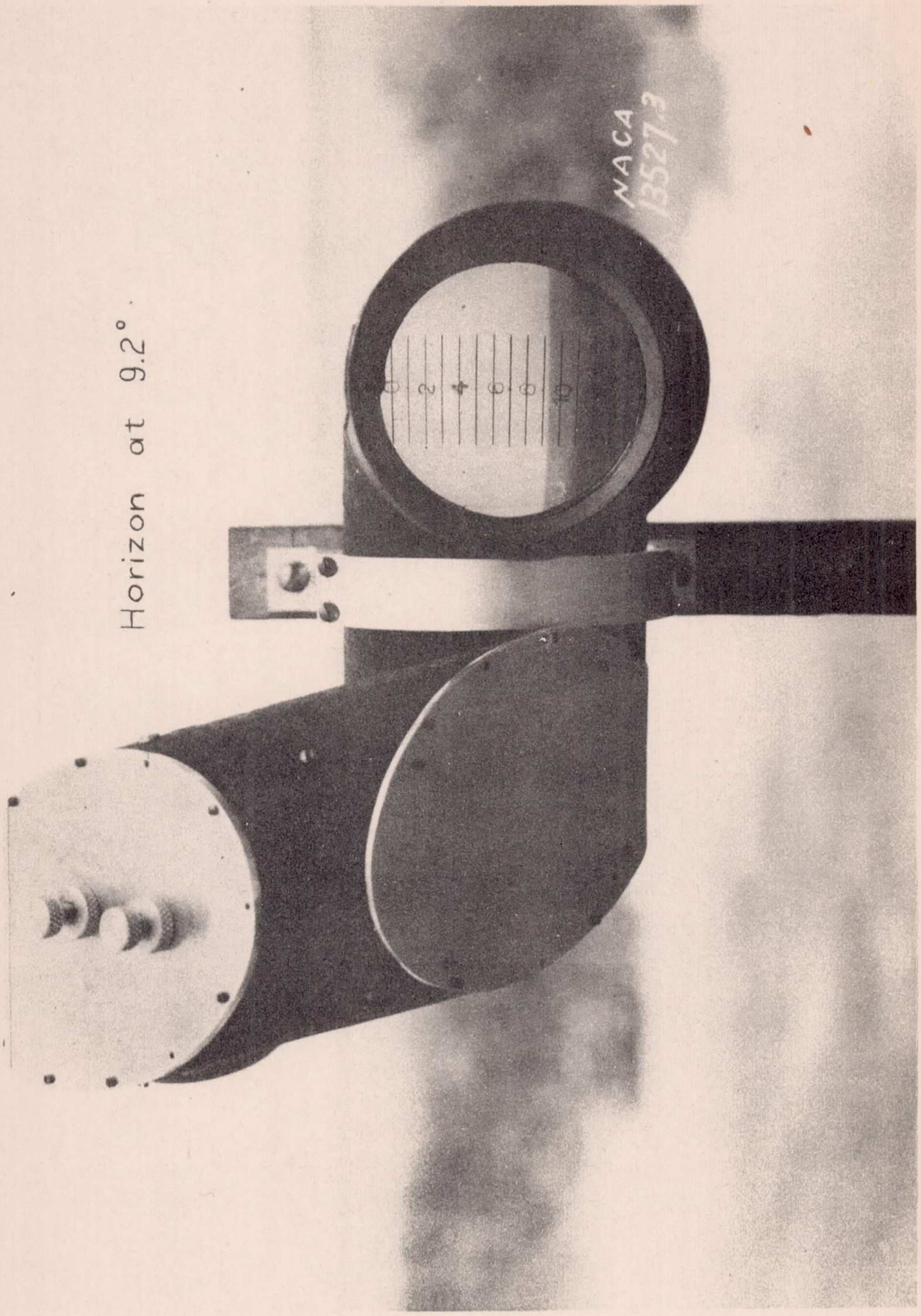


Figure 7.- The NACA trim indicator.

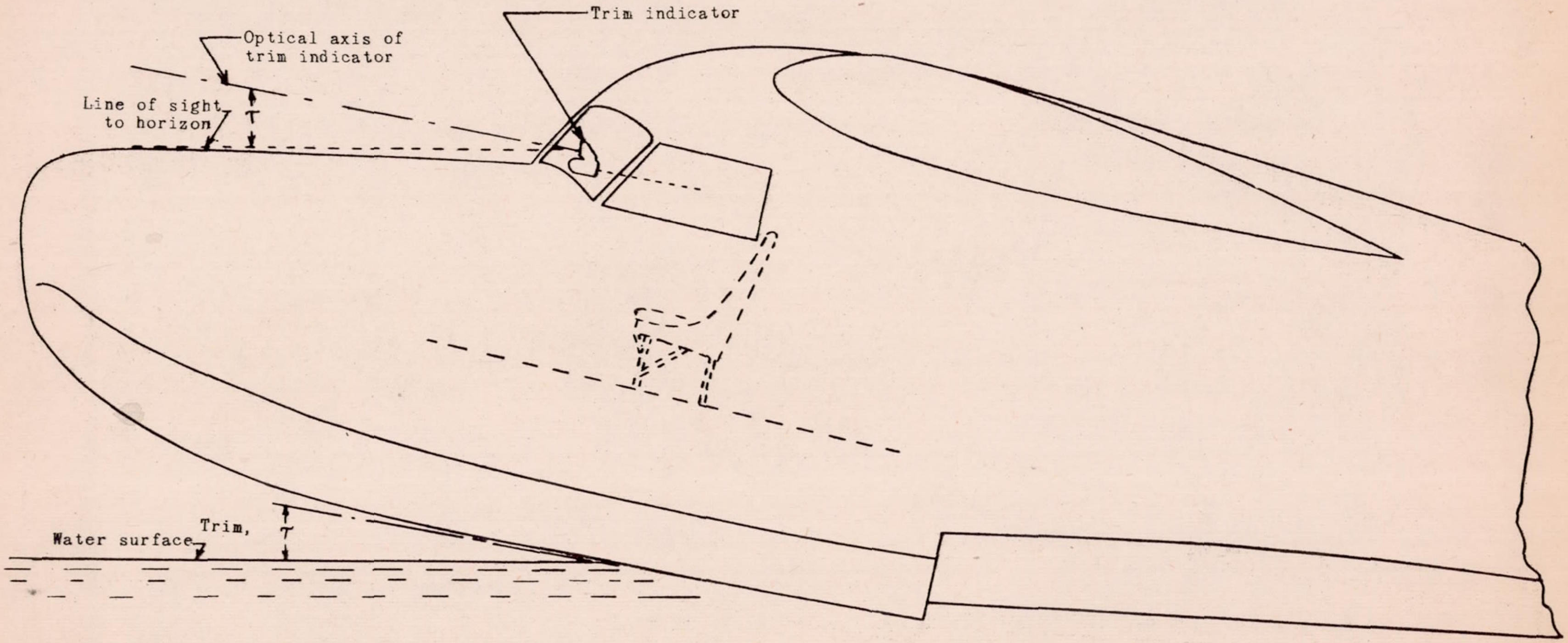


Figure 8.- Position of NACA trim indicator in a flying boat.